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Can tree tilting indicate mechanisms of slope movement?

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ABSTRACT

Slope movements are a common natural hazard. That is why considerable funds are spent annually to limit their effects or to research their prevention. This study evaluates dendrometric approaches as a fast and low-cost alternative to classical methods of slope movement mechanism analysis. A total of 1688 trees growing on the Mazák landslide in the Moravskoslezské Beskydy Mts. and 100 reference trees growing out of the landslide area were analysed. The Mazák landslide is approximately 400 m in length and presents varied morphological features (scarps, rotated blocks, scree slopes, shallow landslide areas, etc.). The slope and direction of stem inclination was recorded for each tree. The results were categorized into four distinct landforms (scarp with outcrops of bedrock, scree slope, front of partial landslide block, plateau of partial landslide block) and were then compared with parameters for the reference trees.

The general model of tree tilting for the landslide area was verified and partially confirmed. Trees growing on the plateau of rotated blocks are predominantly oriented upslope; trees growing on scree slopes of shallow movement and creep are predominantly oriented downslope. Trees growing on rocky scars do not differ significantly from the reference trees. Trees growing from fronts of rotated blocks are oriented both upslope and downslope. From these results, several recommendations regarding dendrometric evidence of slope movement mechanisms are presented: (i) all trees growing on the landslide are to be analysed; (ii) old trees maintain stem tilt intensities and directions for long periods, but young trees are more sensitive to ground movements; (iii) tree root depth influences root sensitivity to movements of various depths; (iv) the general shape of a stem can denote specific mechanisms of slope movement and (v) comparisons with reference trees should always be conducted to exclude potential non-geomorphic effects on tree stem tilt.

1. Introduction

Detailed knowledge of the spatio-temporal activities of landslide movements is crucial for the determination of landslide hazards and for future development modelling. In addition to the chronology and spatial distribution of landslide reactivation, internal structures and mechanisms of movements are currently considered of critical importance in research studies (Massey et al., 2013). Many approaches exist for the assessment of the above-mentioned issues. Various methods of absolute dating (radiocarbon dating, cosmogenic radionuclides, lichenometry, luminescence methods, etc.) can be employed for chronology building (Lang et al., 1999; Pánek, 2015). Spatial activities can be measured directly using data from extensometers (Klimeš et al., 2012) or can be estimated via the time row of detailed DEM (e.g., based on LiDAR data) (Prokešová et al., 2014), digital photogrammetry or via GPS measurement (Mora et al., 2003; Laribi et al., 2015). Internal structures and mechanisms of movements are often reconstructed based on geophysical measurements (Loke et al., 2013; Perrone et al., 2014). The above-listed approaches are limited by temporal accuracy (in the case of dating methods), by long-term monitoring requirements (extensometers) or by limited data accessibility (DEM time rows).

Universal dendrogeomorphic methods are not affected by the above listed limitations (Alestalo, 1971). These methods are based on the principle that trees affected by geomorphic processes (e.g., landslides) react with a specific growth response. Such responses can be identified based on the external morphology of a tree (e.g., bended stems) and based on internal wood structures (e.g., changes in the yearly increment rate) (Shroder, 1978). It is possible to date growth reactions using dendrochronological methods via annual resolution (in some cases, even with seasonal precision). The method is limited only by tree age and by the presence of trees with annual tree rings. The dendrogeomorphic approach is frequently used in research on debris flows (Bollschweiler et al., 2007; Pelfini and Santilli, 2008), rockfall (Stoffel, 2006; Šilhán et al., 2013a), floods (Ruiz-Villanueva et al., 2010; Ballesteros-Cánovas et al., 2011), snow avalanches (Arbellay et al., 2013; Corona et al., 2013), erosion (Gärtner, 2007; Hitz et al., 2008), and landslides (Stefanini, 2004; Lopez-Saez et al., 2012).

While interests predominantly lie in questions concerning the chronology and spatial distribution of processes, whether dendrogeomorphic methods can provide information on landslide movement mechanisms

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must be explored. Stem tilt directions are occasionally used as an indicator of landslide internal structures and movement mechanisms (Braam et al., 1987; Baroň et al., 2004; Fantucci and Sorriso-Valvo, 1999; Šilhán et al., 2013b). For example, Van Den Eeckhaut et al. (2009) interpreted rotational slide movements based on stem tilting directions of a landslide in the Flemish Ardennes. A dendrometric approach based on stem tilt and direction measurements has been used for flood magnitude analysis (Ballesteros-Cánovas et al., 2015) as well. However, verifications of commonly used fundamentals of landslide movement vs. stem tilt direction (magnitude) are still missing. Moreover, existing assumptions are often based on the limited number of trees growing on landslide bodies. Trees tilt during landslide movement is predominantly caused by ground deformations, whereas in the case of floods, debris flows or snow avalanches, tilt is mostly caused by pressures from transported materials. Flood and debris flows can also undercut banks or gully sides. Trees growing along the edge can tilt due to destabilization from undercutting. Previous studies have mainly focused on root plate sizes and soil tension properties under external loads (wind force – Peltola, 2006; snow accretion – Kato and Nakatani, 2000; and rockfall – Stokes et al., 2005). Nevertheless, as noted above, tree tilt during landslides is directly controlled by ground deformations resulting from landslide movements (Harker, 1996; Lopez Saez et al., 2013).

Based on the above noted advantages and ambiguities of the described approaches, this study aims (i) to identify dendrometric tree responses to landslide movements in different areas of a landslide body and (ii) to verify the validity of models of stem inclination for landslide movements and to assess the capacities of dendrometry for mechanisms of landslide movement establishment. If the outlined analysis should prove valid, it must be realized for a large sample size, optimally for all trees growing in a landslide area.

2. Study area

For the purposes of this study, the most active landslide in the culmination of the Moravskoslezské Beskydy was selected (Mazák landslide; 49° 32′ N/18° 26′ E; Fig. 1). The landslide is situated on the SW-oriented slope positioned below the highest peak of the Czech part of the flysch Outer Western Carpathians (Lysá hora Mt., 1323 m a.s.l.). The region is composed of SE-oriented, slightly inclined (10–20°) flysch layers of predominantly massive sandstone (up to 5 m thick) over weak claystone of the late Cretaceous age. The relief is frequently affected by deep seated gravitational slope deformations (Pánek et al., 2011), shallow landslides (Pánek et al., 2009) and by occasional debris flows (Šilhán and Pánek, 2010; Šilhán, 2014). The highest peak (Lysá hora Mt.), is one of the most humid areas in the Czech Republic with mean annual precipitation

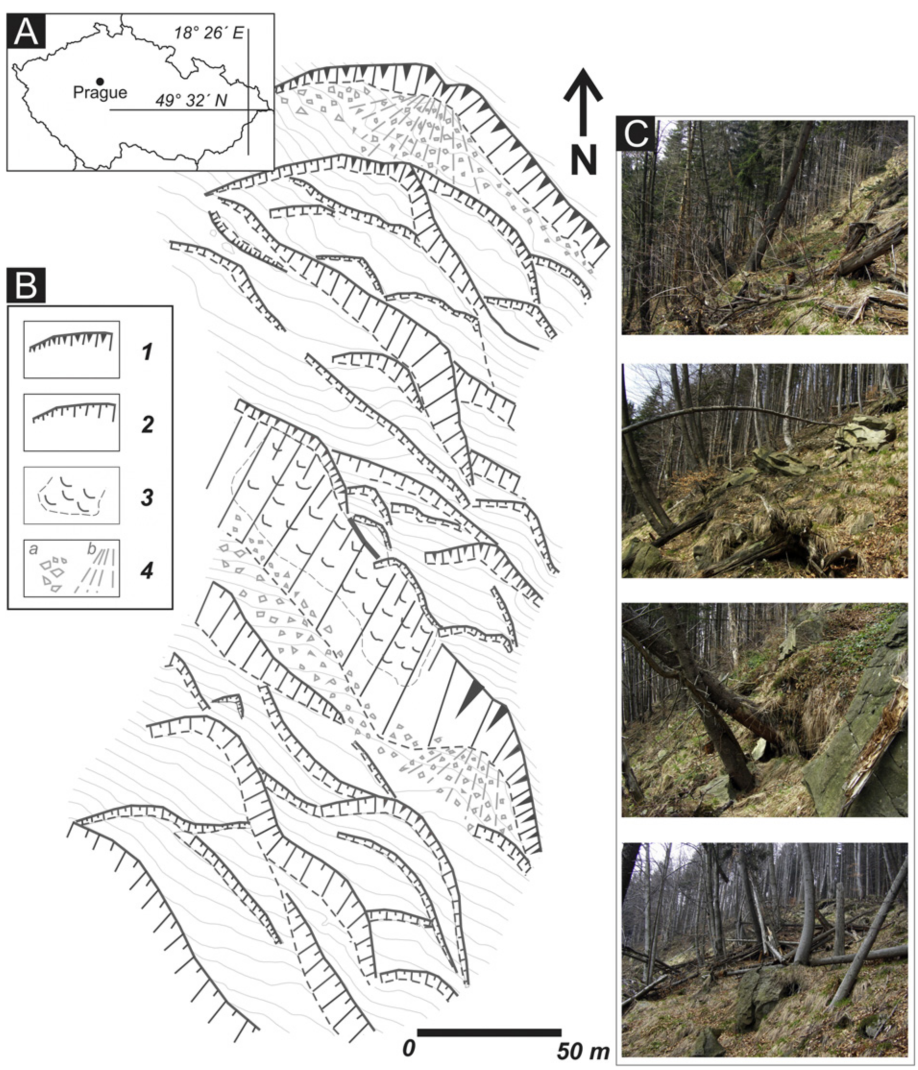

Fig. 1. A — location of the studied landslide in the Czech Republic; B — Geomorphic map of the studied landslide (1 — scarps with outcrops of bedrock, 2 — fronts of partial landslide blocks, 3 — scree slopes and shallow landslides, 4 — scree slopes with (a) — scattered blocks, (b) — talus cones); C — tilted trees in the landslide area.